Note on a Hydrodynamic Model of FG Sge

Note on a Hydrodynamic Model of FG Sge

Mine TAKEUTI

Astronomical Institute, Faculty of Science,
Tôhoku University, Sendai 980

(Received May 2, 1983)

A hydrodynamic model of FG Sge, the central star of a planetary nebula, has been reexamined by using the code with rezoning technique. The pulsation period $P = 29$ days is obtained for the model with the parameters, $M = 1\ M_\odot$, $L = 3200\ L_\odot$ and $T_{eff} = 5500$ K. Stellingwerf's analytical expression is used for the opacities. The calculated amplitude of light variation is 0.45 mag. The growth rate of pulsation is not so great and no strong atmospheric shock waves are found.

Keywords: Stellar pulsation, Hydrodynamic model, FG Sge.

Fadeyev and Tutukov[1] have investigated a hydrodynamical model of FG Sge, the central star of a planetary nebula, and have found the violent motion which yields extended atmospheres. Fadeyev[2] have also found such a violent atmospheric motion in hydrodynamic models of yellow supergiant stars. They found an agreement between the theory of stellar evolution and the observational fact on FG Sge. Besides their results on the evolutionary nature of FG Sge, the behavior of pulsating atmospheres found by them seems very interesting. So another hydrodynamic model of FG Sge has been examined. The purpose of the present note is to describe the result and to compare it with that of Fadeyev and Tutukov[1].

A hydrodynamic model having the mass $M = 1\ M_\odot$, the luminosity $L = 3200\ L_\odot$ and the effective temperature $T_{eff} = 5500$ K has been investigated by using the DYN-code with the rezoning technique, which was originally constructed by Castor, Davis and Davison[3]. The code has been modified partly by Adams and Castor[4] and described also by Davis, Moffet and Barnes[5]. A result obtained by using the DYN-code at Sendai was described in a previous paper (Aikawa et al.[6]). The parameters of the present model were the same as those used in the study on FG Sge by Fadeyev and Tutukov[1]. As the initial value of simulation, the velocity of the outermost layer of -10 km/sec was chosen. The exponent of initial velocity distribution $\underline{n}$ (see eq. (3) in the previous paper[6]) is 6.3. The DYN-code usually suppresses the reflection of strong outward compression waves at the outer boundary, but the suppression was ignored in the present model to fit to that of Fadeyev and Tutukov[1]. The optical depth of the outer boundary is set as 0.0005. The envelope model consisted of 63 zones. About 11 of them were above the layer at $\tau = 2/3$. The temperature at the bottom of the model is $T_i = 0.81 \times 10^6$ K. The ratio of masses of each shell was 1.53. The opacity was calculated by Stellingwerf's analytical formula for the population I mixture ($X = 0.70$, $Y = 0.28$ and $Z = 0.02$)[7], while Fadeyev and Tutukov used the Cox-Stewart opacities for the Massevitch II mixture ($X = 0.70$, $Y = 0.28$ and $Z = 0.02$, but the abundance of iron is different from Stellingwerf's one)[8].

For the hydrodynamic model described here, the maximum kinetic energy of pulsation K.E.max decreases in the course of computation without pumping. At the time 5×10^7 sec after the start, the pulsation seems to close its periodic oscillation, although the pulsation still continue damping. The period is approximately 29 days consistent with Fadeyev and Tutukov's model, while the full amplitude of photospheric velocity is nearly 10 km/sec, which is a tenth of their result. K.E.max is approximately 3×10^{40} erg. The amplitude of luminosity is close to 0.45 mag. No atmospheric violent motion is found.

Compared with the results of Fadeyev and Tutukov[1], the present model shows some different features. First, the growth rate of pulsation is nearly zero with the initial velocity given in the present simulation, while that of Fadeyev and Tutukov is about 0.5. The difference in excitation probably came from the difference in opacities employed, because Fadeyev and Tutukov once found the model pulsationally stable with the Cox-Tabor opacities for the King IV A mixture[9], while the oscillation is strongly unstable with the Cox-Stewart opacities for the Massevitch II mixture[10]. Second, in consequence of small amplitude no strong shock waves are found and the atmosphere does not expand to distant region from the photosphere. Although non-synchronous behavior is found for the outermost shell, any drastic outward motion is not observed. So the violent phenomenon possibly expected in atmospheres of yellow supergiant stars cannot be investigated in the present simulation.

Finally we may note here that the observational amplitude of light variation (e.g. reported by Arkhipova et al.[12]) is approximately 0.5 mag. This makes us an implication that the results of the present calculation fit to the observational data, while the strong instability found in the model of Fadeyev and Tutukov is favorable to the rapid increase of pulsation observed in FG Sge. The coincidence of the pulsation period between the present model and Fadeyev and Tutukov's one allows us to regard the result of Fadeyev and Tutukov on the evolutional state of FG Sge as correct.

The author wishes to express his thanks to Drs. A.V. Tutukov and Yu.A. Fadeyev for their kind discussions on the hydrodynamical study of pulsating stars. He also wishes to thank to Professor Y. Tanaka of Ibaraki University for discussions. The computation was carried out at the Computer Center of Tôhoku University. This work was supported in part by the Grant-in-Aid for Co-operative Research of the Ministry of Education, Science and Culture under Grant No. 57340024.

References

1) Yu.A. Fadeyev and A.V. Tutukov: Mon. Not. R. astr. Soc. 195 (1981) 811.
2) Yu.A. Fadeyev: Astrophys. Space Science 86 (1982) 143.
3) I.J. Castor, C.G. Davis and D.D. Davison: Los Alamos Scientific Laboratory Report, LA-6644 (1977).
4) T.F. Adams and I.J. Castor: Astrophys. J. 230 (1979) 826.
5) C.G. Davis, T.J. Moffett and T.G. Barnes: Astrophys. J. 246 (1981) 914.
6) T. Aikawa, K. Uji-Iye, T. Okuda and M. Takeuti: Science Reports Tôhoku Univ. Eighth Ser. 3 (1982) 82.
7) R.F. Stellingwerf: Astrophys. J. 195 (1975) 441.
R.F. Stellingwerf: Astrophys. J. 199 (1975) 705.
8) A.N. Cox and J.N. Stewart: Nauchn. Inf. 157 (1969) 1157.
9) A.N. Cox and J.E. Tabor: Astrophys. J. Suppl. 31 (1976) 271.
10) Yu.A. Fadeyev: private communication.
11) e.g. V.P. Arkhipova, G.V. Zaitseva, R.I. Noskova and M.V. Saveljeva: Astr. Tsirk. 987 (1978), V.P. Arkhipova, G.V. Zaitseva and R.I. Noskova: Astr. Tsirk. 1111 (1980), 1217 (1982).